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PROPERTIES OF COASTAL WATERS AROUND THE US: PRELIMINARY RESULTS USING MERIS DATA

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ABSTRACT

MERIS imageries over coastal waters around the United States were ordered from ESA. These data either reveal enormous phytoplankton blooms (chlorophyll concentrations in the range of 100 – 1000 mg/m^3) or turbid river plume waters or optically shallow environments. We used in situ measurements to validate remote-sensing reflectance derived from MERIS. Further, we applied algorithms designed for optically deep or optically shallow waters, respectively, to derive water and/or bottom properties of the study area. The derived results were found consistent with in situ measurements or known values. Discussions were also provided regarding remaining issues related to MERIS data. These exercises and results demonstrate the great potentials and capabilities of using MERIS data to monitor water environments in coastal regions.

1. INTRODUCTION

Coastal ecosystems are the most productive areas of the global oceans. They are located commonly in close proximity to urban, industrial, and agricultural stressors, frequently affected by phytoplankton blooms (sometimes toxic) and severe storms and hurricanes. Effective management of such coastal regions requires continuous monitoring of the various water properties, where satellite remote sensing provides synoptic, repeated, measurements that are not possible with traditional field or laboratory techniques [1].

Satellite remote sensing of water properties relies on the measurements of ocean color radiometry (OCR) or spectral water-leaving radiance that emerges from the water surface. Generally, the water-leaving radiance is a nonlinear sum of signals from phytoplankton, colored dissolved organic matter (CDOM), and suspended sediments, and bottom reflectance when the bottom optically shallow. For such complicated optical systems, the current SeaWiFS and MODIS sensors, due to their limitations in sensor's spectral and spatial configurations (6-8 spectral bands and 1 km spatial resolution), have difficulties in revealing the detailed spatial variation in coastal ecosystems and separating the effects resulted from bottom reflectance. The MERIS sensor, launched by ESA in February 2002, has 15 spectral bands in the visible domain and capable to collect data with a 300 m spatial resolution. Such improved spatial and spectral configurations provide much better potentials for observing complex coastal waters, for example to derive bottom depth over optically shallow waters [2].

However, because it was launched recently, it is not clear yet how MERIS performs in terms of deriving water properties, especially for coastal waters. It is essential to calibrate and validate the products derived from MERIS before it is put into routine and operational applications. For this overall objective, MERIS full-resolution (300 m) data around the US coasts were ordered from MERIS Support Center. These data were processed with algorithms developed for optically deep and optically shallow waters, with preliminary results presented here.

2. DATA

Both Level-1b and Level-2, full-resolution, MERIS data over the West Florida Shelf (Oct. 21, 2003), the Great Bahamas (Dec. 14, 2004), the Monterey Bay (Sept. 11, 2006), and the northern Gulf of Mexico (Feb. 6, 2007) were ordered through the ESA Earth Observation Missions. Figure 1 presents pseudo-true color images of the research areas. While data of WFS and GB covers both optically deep (e.g., tongue of the ocean) and optically shallow waters (the Florida Bay and the Bahamas Bank), data of MB covers enormous phytoplankton bloom, and data of GOM covers waters from oceanic to near shore waters dominated by re-suspended sediments. Clearly, these MERIS images cover wide dynamic range of waters. For imagery over GOM and MB, remote-sensing reflectance (R_{rs}) and water's absorption (a) and attenuation (c) coefficients were also collected in situ. R_{rs} was measured by a custom-made hand-held spectrometer; while a and c were measured by an AC-9 instrument of the Wetlabs, Inc.

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Both measurements and data processes followed the designated technical protocols [3].

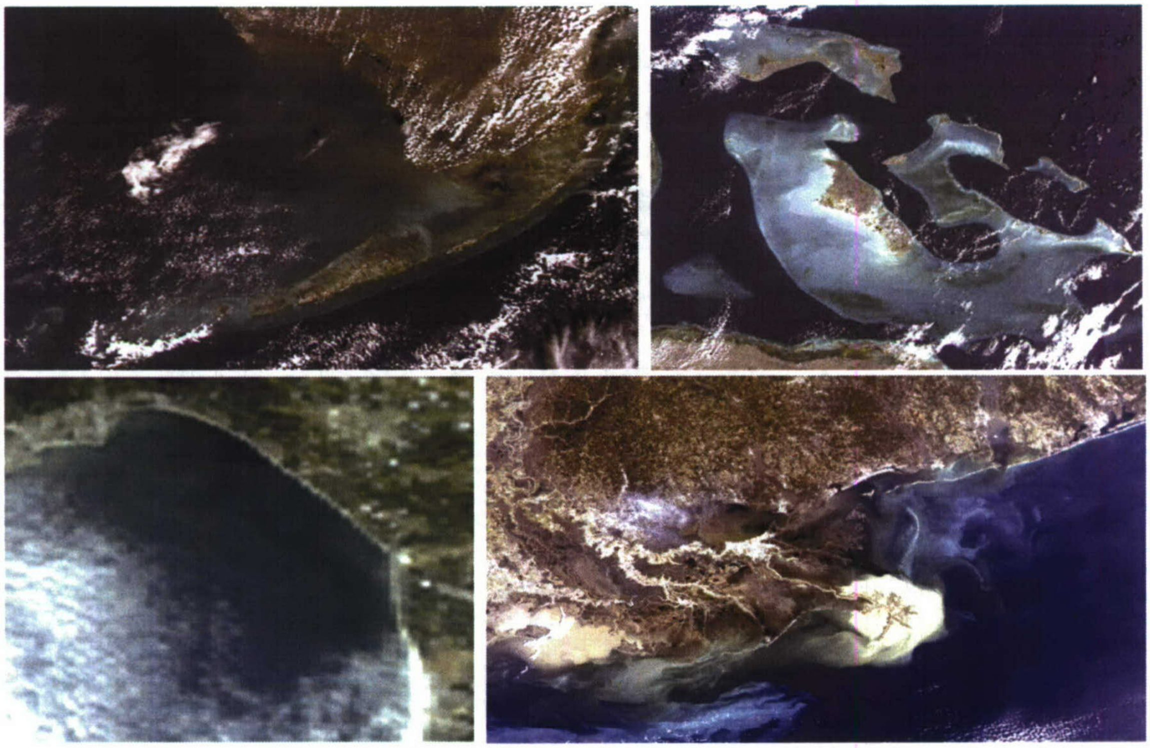

Figure 1. MERIS images collected over waters around the US coasts. Top left: West Florida Shelf (Oct. 21, 2003); top right: the Bahamas (Dec. 14, 2004); bottom left: Monterey Bay (Sept. 11, 2006); bottom right: northern Gulf of Mexico (Feb. 6, 2007)

3. DERIVATION OF WATER AND BOTTOM PROPERTIES

To get water and/or bottom properties of the study areas, the Quasi-Analytical Algorithm [4] developed for optically deep waters and the spectral optimization algorithm developed for optically shallow waters [5, 6] were applied, respectively. The QAA was originally designed to process data from SeaWiFS and MODIS sensors, here a slight modification was made (for the derivation of absorption coefficient at the reference wavelength, 560 nm) to accommodate with the MERIS spectral configurations.

4. RESULTS AND DISCUSSIONS

4.1. Validation of MERIS remote-sensing reflectance

Remote-sensing reflectance (R_{rs}, sr^{-1}) is defined as the ratio of water-leaving radiance to downwelling irradiance just above the water surface, which is a factor of smaller than the reflectance value provided with MERIS Level-2 products. MERIS reflectance was first converted to R_{rs} and then compared with in situ R_{rs}. Figure 2 shows the measurements made in Monterey Bay and in the Gulf of Mexico. Although large discrepancies appeared at Band 1 (411 nm), it is found that MERIS R_{rs} values were generally consistent with that from in situ measurements, even for such near-shore, complex waters where data from many other sensors were simply flagged or masked. It is worth noting that St.11 of the Monterey Bay was in an enormous phytoplankton bloom, with chlorophyll concentration measured fluorometrically ~500 mg/m^3.

4.2. Spatial distribution and variation of environmental properties derived from MERIS

Figure 3 shows the distribution of chlorophyll fluorescence line height (FLH) of the Florida Bay and adjacent waters derived from the MERIS data. For the complex water environments (especially the Florida Bay), chlorophyll concentration derived from conventionally simple band-ratio algorithm is frequently contaminated by effects of bottom reflectance (see below). The FLH measured in the near-IR effectively avoided such contamination, and more accurately showed the spatial variations of chlorophyll concentration, as validated by near-concurrent measurement in the same area by the NOAA Atlantic Oceanographic and Meteorological Lab.

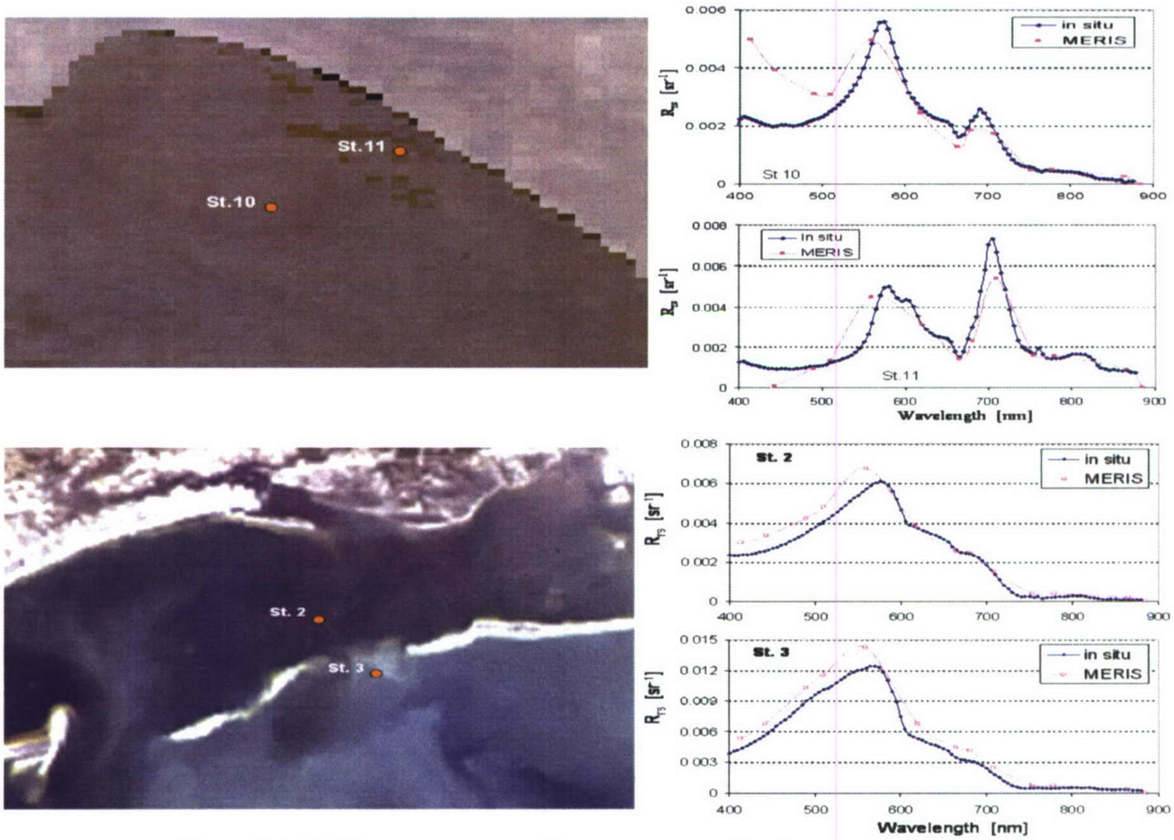

Figure 2. MERIS remote sensing reflectance compared with in situ measurements. Top: Monterey Bay, Sept.11, 2006; bottom: northern Gulf of Mexico, Feb. 6, 2007.

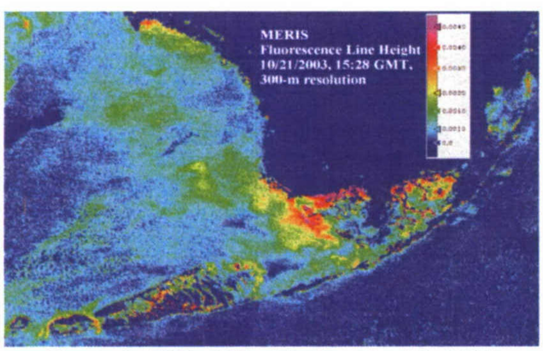

Figure 3. FLH of Florida Bay, Oct.21, 2003.

The waters of Bahamas belong to optically shallow domain, where the values of R_{rs} are nonlinear mixture of contributions from both the water column and the bottom. To accurately derive properties of the water column, it is necessary to correct the bottom effects; or, vice versa, it is necessary to know the water properties in order to effectively derive properties of the bottom [7].

The MERIS R_{rs} imagery of Bahamas was fed to HOPE, a hyperspectral-optimization-process-execution module developed based on the hyperspectral algorithm of Lee et al. [5, 6]. Figure 4 (left) shows the bathymetry image derived from MERIS. For the Bahamas area, the bathymetry is generally less than ~10 m, with a few places as deep as 20 m. These results are consistent with historical bathymetry surveys.

Figure 4 (right) shows the bathymetry image delivered along the MERIS data, where bathymetry is in very crude spatial resolution (~2km). Clearly, the imagery derived from MERIS spectral data shows significantly enhanced details in bathymetry variation. More importantly, the many missing shallow (< ~10 m) regions in the coarse bathymetry data (outlined in black circles in the image) were successfully recovered.

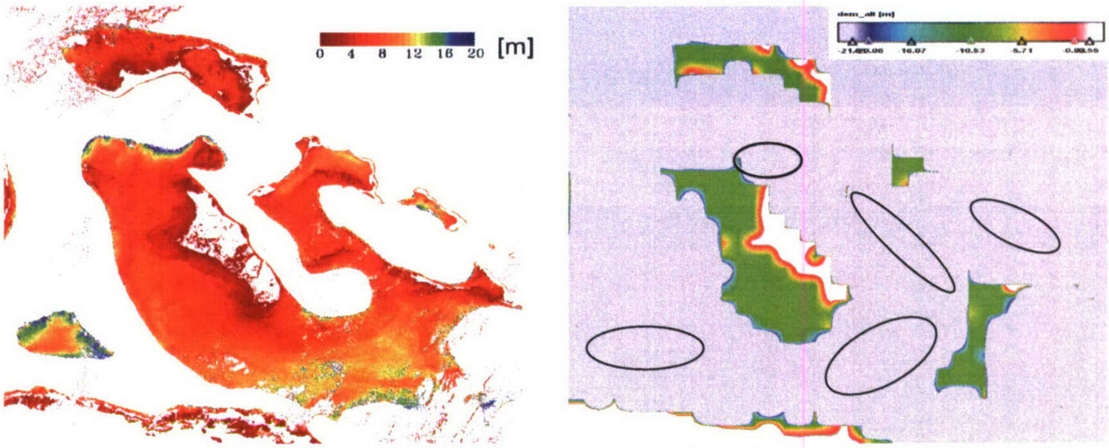

Figure 4. Bathymetry derived from MERIS (left) R_{rs}( ) compared with bathymetry provided with MERIS

Figure 5 shows the total water absorption coefficient at 443 nm ($a(443)$) derived by HOPE versus the concentration of chlorophyll derived by a simple band-ratio algorithm [8] (in essence, it is the nonlinearly scaled total absorption coefficient [9]). $a(443)$ measures the combined contribution at 443 nm from that of water molecules, CDOM, phytoplankton, and other non-living particles (detritus and suspended sediments). From MERIS, $a(443)$ is generally centered around 0.045 m^{-1}, and nearly uniform across the deep and shallow regions of the great Bahamas. These results are consistent with the generally considered 'clearest' water in the natural environment [10] and the constant mixing by tides and currents between the shallow and deep waters. The most striking result is that $a(443)$ is almost completely de-coupled from the bathymetry. In contrast, because of the bottom contribution to the observed water-leaving radiance, significantly enhanced (a factor of ~10) but false chlorophyll concentration is found for waters in the shallow Bahamas Bank when compared to waters of the adjacent deep area. This type of false, high chlorophyll feature is common in the present satellite ocean-color data products over optically shallow waters.

For Monterey Bay and the northern Gulf of Mexico, MERIS data were fed to the QAA procedure to retrieve total absorption and particle backscattering coefficients. Figure 6 shows the derived results. For MB, $a(443)$ ranged between 0.1 and 2.0 m^{-1} while $b_{bp}(443)$ ranged between 0.01 and 0.1 m^{-1} (greater values were obtained when the spectral optimization scheme was applied for the bloom waters, results not shown here). For the two stations shown in Fig.2, $a(443)$ values derived from MERIS were ~3.9 m^{-1} at St.11 and ~ 0.3 m^{-1} at St.10. In addition, elevated backscattering is evident for the near shore and bloom waters (Fig.6, top).

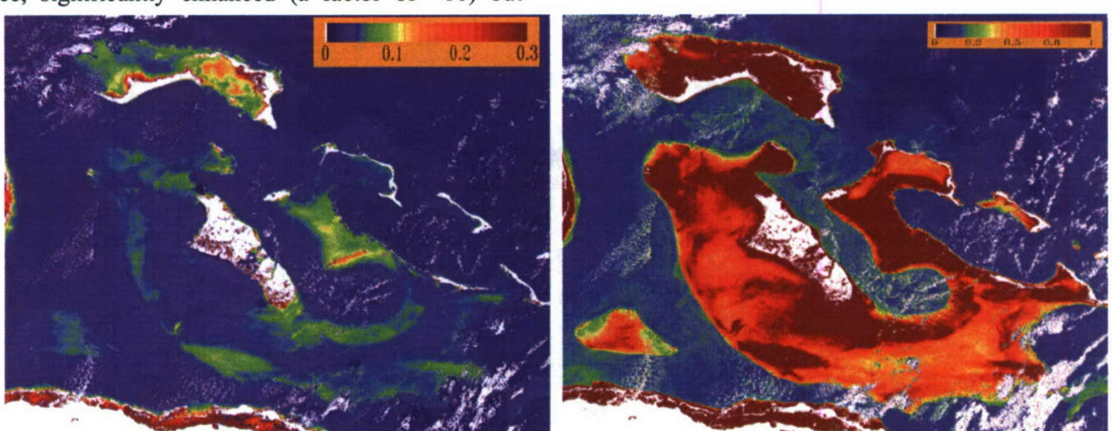

Figure 5. Left: $a(443)$ (m^{-1}) derived from HOPE with bottom effects corrected; Right: chlorophyll concentration (mg/m^3) derived from an operational empirical algorithm.

Similarly, the GOM data showed enhanced absorption and backscattering coefficients for near-shore waters, a result of river discharge and resuspension of sediments, respectively. More interestingly, there is a patch of water in the lower portion of the image (annotated on Fig.6; the 'white patch' in Fig.1, bottom right) with significantly elevated backscattering. This patch does not appear to be an extension of the nearby sediment-dominant waters where both absorption and backscattering are high. This white patch is of similar backscattering coefficients but much lower absorption coefficients, which has apparently the characteristics of a bloom of coccolithophores [11], but unfortunately there was no in situ data for its validation.

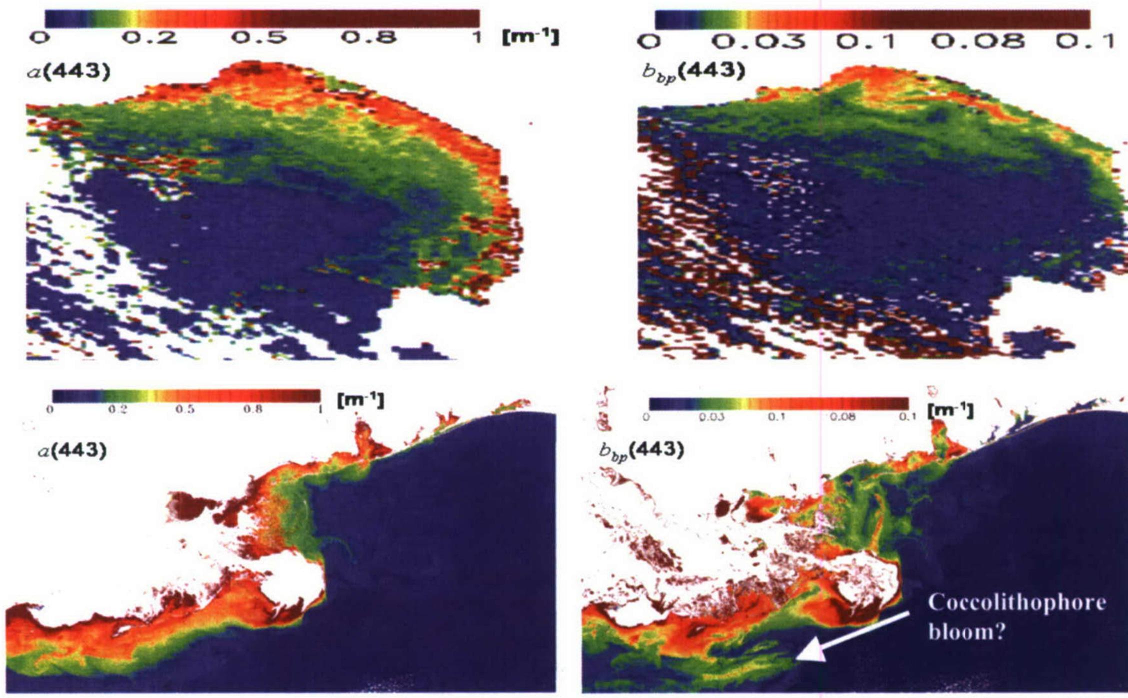

Figure 6. Spatial variation of total absorption and particle backscattering coefficients derived from MERIS. Top: Monterey Bay, Sept.11, 2006; bottom: northern Gulf of Mexico, Feb. 6, 2007.

We also tested the MERIS Case-2 Regional Processor (MERIS C2R-v1.1, an Artificial Neural Network scheme) [12] developed for coastal waters, with promising results, although sometimes with bigger uncertainties, found for data in this study (not presented here).

5. SOME REMAINING ISSUES

In addition to the significant success in deriving water and bottom properties of complex coastal regions, there exist uncertainties in the current MERIS data. Such uncertainties include residual errors in correcting sun glint, and excessive high reflectance values in the blue bands. As an example, for MERIS image collected on Feb. 6, 2007 over the northern Gulf of Mexico, Figure 7 shows observed values before (top) and after (bottom) atmosphere correction for two groups of pixels at Pt.1 and Pt.2, respectively. For each group, the differences in the top-of-atmosphere radiance were quite small (see Fig.7, top), but the differences were found quite large in the derived reflectance after atmospheric correction (see Fig.7, bottom). Such differences will then propagate to water properties, with most of the errors transfer to derived backscattering coefficient (which depends directly on the magnitude of R_{rs}), as showing the lower right corner of Figure 6 (right).

6. SUMMARY

From this preliminary evaluation of MERIS data for a wide range of coastal waters around the United States, it is found that the sensor calibration and the atmosphere correction algorithm worked reasonably well, even for such complex coastal waters, although sometimes water-leaving radiance in the blue bands appeared erroneously high. By applying algorithms developed for optically deep and optically shallow waters, respectively, coastal water properties were derived very well, especially for shallow waters. These results indicate that the algorithms are effective in processing MERIS data. MERIS data are found particularly useful to derive fine-resolution bathymetry for optically shallow waters, which has not been available from historical surveys. These results demonstrated that MERIS data, particularly those at full resolution, are of great value for monitoring the complex coastal ecosystems and/or lakes, which otherwise is difficult with other satellite sensors designed for ocean color radiometry.

7. ACKNOWLEDGEMENT

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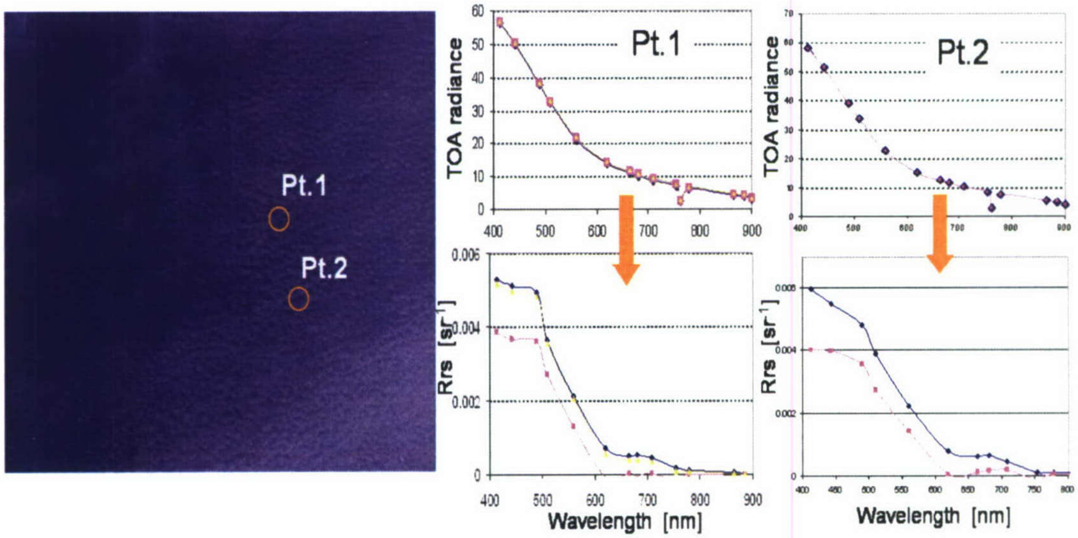

Figure 7. Left: MERIS Level-1 true color image over the northern Gulf of Mexico on Feb.6, 2007. Top right: Top of atmosphere radiance for pixels at Pt.1 and Pt.2, respectively; Bottom right: Derived remote-sensing reflectance for pixels at Pt.1 and Pt.2.

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